Student Textbook pages 424–427

Answers to Understanding Concepts Questions

1. An endothermic reaction is one where more energy is required to break the bonds of the reactants than is released in the formation of the bonds of the products.
2. Since there is twice as much liquid in beaker B, the temperature change (Δt) will be one-half that of beaker A.
3. **(a)** endothermic
   (b) exothermic
   (c) endothermic
   (d) exothermic
   (e) exothermic
4. The standard molar enthalpy of formation for all elements in their standard state is zero. Absolute enthalpy cannot be measured. Since enthalpy is always measured as a change, the reference point can be set wherever it is convenient, as long as it is consistent. Therefore, chemists decided to reference all potential energy relative to elements that are given a molar enthalpy of zero.
5. System is referring to the objects that are being studied, and whose enthalpy change will be measured and/or calculated. The surroundings, on the other hand, include all objects other than the system. The system usually includes the calorimeter; and the reactions taking place inside the calorimeter, the surroundings would be the air, the thermometer (unless its enthalpy change is included in the calculations), and the stirring rod.
6. If the reactants have more potential energy than the products, then the reaction is exothermic, since the additional energy that was in the reactants was released to the surroundings in the formation of the lower energy products.

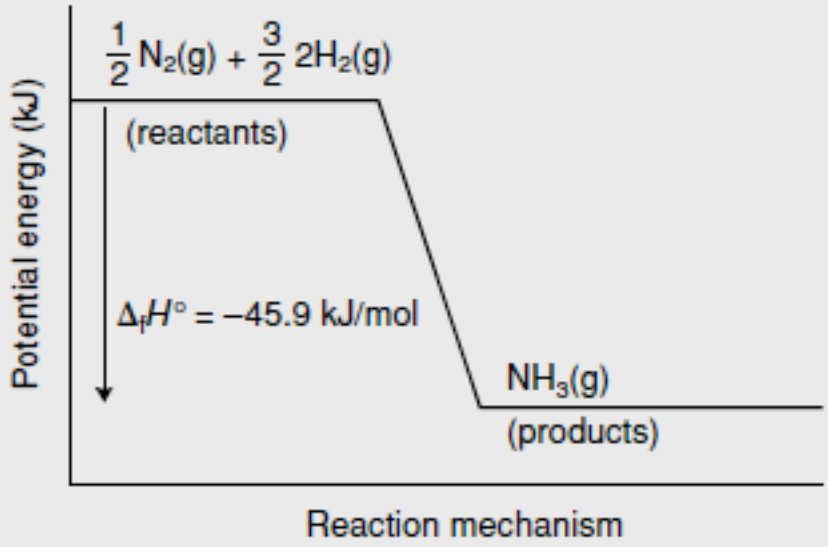
7. Photosynthesis and cellular respiration are the reverse of each other. Photosynthesis stores the energy originating from the Sun in the chemical bonds of glucose. Cellular respiration harnesses that energy through the combustion of glucose in the cells of living things. Photosynthesis takes place only in plants, some bacteria and some protists, whereas cellular respiration takes place in all living things.
8. In an open system, the water produced through hydrocarbon combustion will be gaseous ($H_2O(g)$), whereas in a closed system, the water produced will be in liquid form ($H_2O(\ell)$).
9. The energy stored in chemical bonds originates almost entirely from the Sun. The Sun's energy is trapped in glucose through photosynthesis. The energy stored in the chemical bonds in glucose is released through photosynthesis to be used by living things. The sun's energy is also the driving force in generating electricity through hydroelectricity, wind power and in burning fossil fuels.
10. Enthalpy is the total internal energy of a substance at constant pressure. Molar enthalpy is the quantity of thermal energy absorbed or released when one mole of the substance undergoes a potential energy change.
11. The higher the specific heat capacity of a substance, the more energy is required to increase the temperature of that substance. Therefore, given a constant rate of energy input, platinum, which has the lowest specific heat capacity, will reach 30 °C with the least amount of energy input and therefore the least amount of time. Similarly, titanium has the highest specific heat capacity so it will require the largest amount of energy input and therefore the longest amount of time to reach 30 °C.

12. (a) $\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \rightarrow NH_3(g)\ \Delta_f H^\circ = -45.9\ kJ/mol$

$\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \rightarrow NH_3(g) + 45.9\ kJ$

(b)

Potential energy diagram for the formation of ammonia, $NH_3(g)$



13. Calorimetry is the technological process of measuring the heat released or absorbed during a chemical or physical process. The most commonly used calorimeter is a simple calorimeter which consists of two nested polystyrene cups with a lid. This calorimeter can be used for reactions taking place in solution. To measure enthalpies of combustion, a calorimeter can be constructed from an aluminium can. The can is filled with water and suspended above the fuel. When the fuel is burned, it will heat up the metal and the water.

14. If the calorimeter absorbs a significant amount of heat, then it must be included in the calculations. To include the heat absorbed by the calorimeter, its heat capacity must be known.

15. Specific heat capacity is defined as the quantity of energy required to raise the temperature of 1 g of the substance by 1 °C. Heat capacity is defined as the quantity of energy required to raise the temperature of that object by 1 °C.

(a) The units for specific heat capacity are J/g•°C, for heat capacity, J/°C.

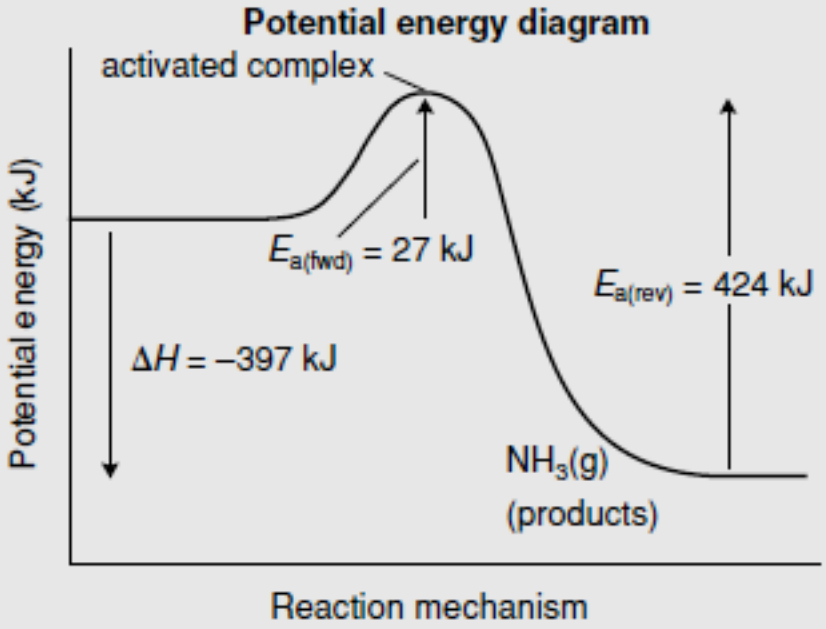
(b) Specific heat capacity is used for pure substances, whereas heat capacity is usually used to calculate heat for calorimeters, which may be made of a variety of substances. Its heat capacity will be calibrated using materials of known specific heat capacity.

16. Activation energy, E_a, is the minimum energy that a collision must have for a reaction to take place.

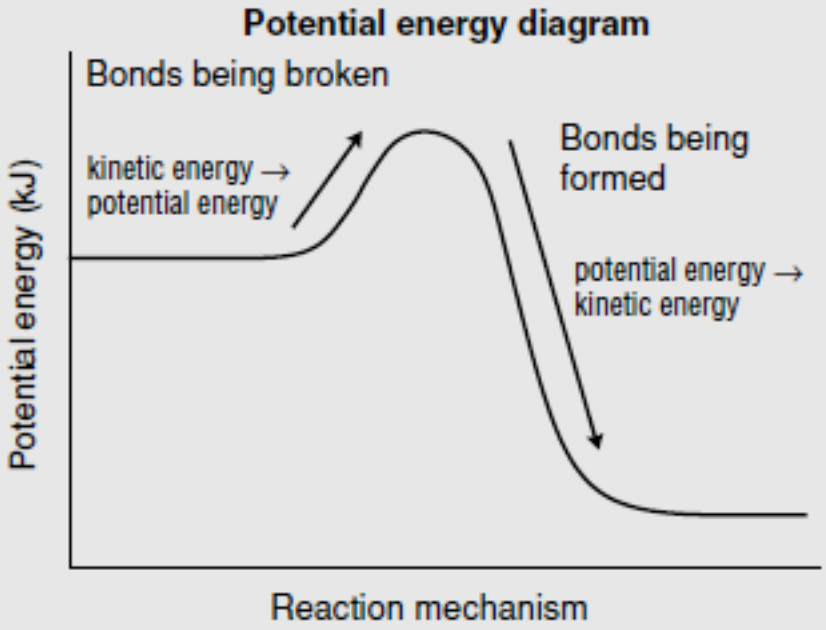
17. For a reaction to occur, molecules must collide with the correct collision geometry and with sufficient energy (activation energy).

18. Catalysts provide a lower energy pathway for the reaction, thereby lowering the activation energy. If the activation energy is lowered, more collisions will have sufficient energy for a reaction to occur and therefore the reaction should proceed more quickly.

19.



20.



21. Enzymes and catalysts both speed up reactions and are regenerated at the completion of the reaction. Enzymes are extremely large molecules that only operate well at

temperatures found in living systems, while catalysts are small molecules, often ions, that are not adversely affected by temperature.

22. Both heat content and heat of combustion describe the quantity of energy released when a substance is burned. Heat content is measured in kJ/kg and is useful in the discussion of energy content in practical applications since fuels would be commonly purchased by mass (or perhaps volume). Heat of combustion is measured in kJ/mol. This value is more applicable in situations where moles are used, that is, in a chemistry lab.

Answers to Applying Concepts Questions

23. When NaOH(s) and HCl(aq) are mixed, the acid will be neutralized by the base. The increase in temperature represents the enthalpy of neutralization.

24. Students should design an experiment similar to Investigation 9.B on pages 358–359 of the student textbook.

25. **(a)** $2C(s) + 2H_2(g) + O_2(g) \rightarrow CH_3COOH(\ell)$ $\Delta_f H^\circ = -484.3$ kJ/mol

(b) $Ba(s) + \frac{1}{8}S_8(s) + 2O_2(g) \rightarrow BaSO_4(s)$ $\Delta_f H^\circ = -1473.2$ kJ/mol

(c) $2C(s) + H_2(g) \rightarrow C_2H_2(g)$ $\Delta_f H^\circ = 227.4$ kJ/mol

(d) $\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g)$ $\Delta_f H^\circ = 33.2$ kJ/mol

26. The more thermally stable a compound, the more energy is required to decompose the substance. Therefore, the least thermally stable has the highest molar enthalpy of formation; the most thermally stable has the lowest molar enthalpy of formation. Ranked from the least thermally stable to the most thermally stable: $C_2H_2(g)$, $NO_2(g)$, $CH_3COOH(\ell)$, $BaSO_4(s)$.

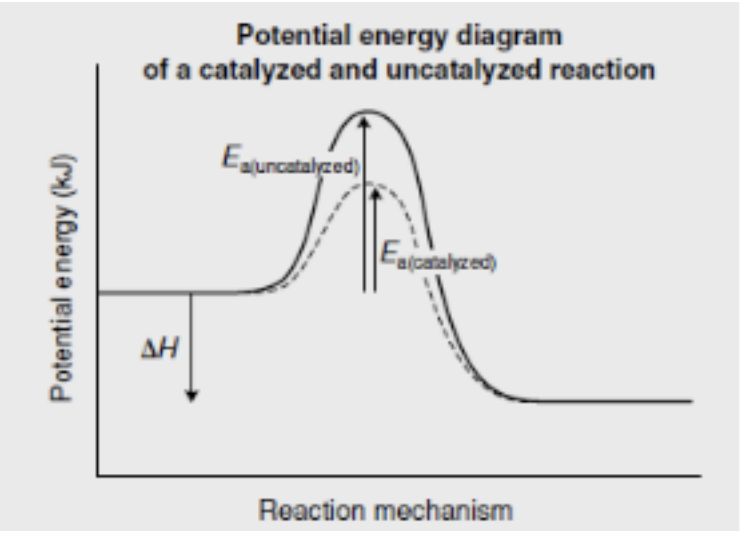
27. It is more efficient to produce electricity from flowing water than from burning fossil fuels because there are fewer energy conversions. Although energy is conserved, with each energy conversion, some energy is "lost" to a form of energy that is not useful. The energy in falling water is converted to electricity in only one conversion, whereas the production of electricity from fossil fuels involves at least two energy conversions, not to mention the mining and transportation of the fossil fuels to the power plant.

28. (a) The expected yearly consumption is 648 kWh.

(b) This model is better than average. The most energy efficient model uses approximately 56 kWh annually, and the least energy efficient model uses 972 kWh annually.

(c) The most energy efficient models will have an ENERGY STAR™ logo.

29. (a) A catalyst has no effect on the enthalpy change of a reaction since it affects only activation energy, and therefore reaction rate. As you can see from the figure below, a catalyst does not change the enthalpy of the reactants and the products which are the only conditions that will affect ΔH.



(b) Student procedures should be similar to Investigation 11.A on page 417 of the student textbook. In order to measure the enthalpy change as well as the effect of a catalyst, students should include a step where they measure the initial and final temperatures of the system.

(c) $H_2O_2(aq) \rightarrow H_2O(\ell) + \frac{1}{2}O_2(g)$

$$\Delta_r H = [1(\Delta_f H^\circ\ H_2O(\ell)) + \frac{1}{2}(\Delta_f H^\circ\ O_2(g))] - [1(\Delta_f H^\circ\ H_2O_2(aq))]$$

$$= [(1\text{ mol})(-285.8\text{ kJ/mol}) + \left(\frac{1}{2}\text{ mol}\right)(0\text{ kJ/mol})] - [(1\text{ mol})(-187.8\text{ kJ/mol})]$$

$$= -98.0\text{ kJ/mol}$$

Answers to Solving Problems Questions

30. (a) $\Delta t = 18.3\ ^\circ C - 15.7\ ^\circ C$

$= 2.6\ ^\circ C$

mass of ethanol $= 47.39\text{ g} - 47.19\text{ g}$

$= 0.20\text{ g } C_2H_5OH(\ell)$

mass of water $= 239.36\text{ g} - 84.37\text{ g}$

$= 154.99\text{ g}$

$$E_{system} = E_{surroundings}$$

$$n\Delta_c H = -(mc\Delta t_{water} + mc\Delta t_{aluminium})$$

$$\Delta_c H = -\frac{(mc\Delta t_{water} + mc\Delta t_{aluminium})}{n}$$

$$= -\frac{(154.99\ \cancel{g})\left(\frac{4.19\text{ J}}{\cancel{g}\cdot\cancel{^\circ C}}\right)(2.6\ \cancel{^\circ C}) + (84.37\ \cancel{g})\left(\frac{0.897\text{ J}}{\cancel{g}\cdot\cancel{^\circ C}}\right)(2.6\ \cancel{^\circ C})}{(0.20\ \cancel{\text{g } C_2H_5OH(\ell)})\left(\frac{1\text{ mol } C_2H_5OH(\ell)}{46.08\ \cancel{\text{g } C_2H_5OH(\ell)}}\right)}$$

$$= -\frac{1.885\ \text{kJ}}{0.0043\ \text{mol}\ C_2H_5OH(\ell)}$$

$$= -4.4 \times 10^2\ \text{kJ/mol}\ C_2H_5OH(\ell)$$

(b) $$\%\ \text{difference} = \left| \frac{\text{accepted} - \text{experimental}}{\text{accepted}} \right| \times 100\%$$

$$= \left| \frac{-507\ \cancel{\text{kJ/mol}} - (-440\ \cancel{\text{kJ/mol}})}{-507\ \cancel{\text{kJ/mol}}} \right| \times 100\%$$

$$= 13\%$$

(c) The "lost" energy was converted into forms other than heat such as light, or it was lost to the surroundings, heating up the air and the burner.

31. Method 1 Using Formulas

Find the number of moles of CaO(s) reacted

$$n = \frac{m}{M}$$

$$= \frac{1.0 \times 10^2\ \cancel{\text{g CaO(s)}}}{\frac{56.08\ \cancel{\text{g CaO(s)}}}{\text{mol CaO(s)}}}$$

$$= 1.78\ \text{mol CaO(s)}$$

Determine the amount of energy released when that amount of CaO(s) reacts

$$\Delta H = n\Delta H^\circ$$

$$= (1.78\ \cancel{\text{mol CaO(s)}})\left(\frac{-65\ \text{kJ}}{\cancel{\text{mol CaO(s)}}}\right)$$

$$= -1.16 \times 10^2\ \text{kJ}$$

Determine the number of moles of methane that would produce that amount of energy

$$\Delta H = n\Delta H^{\circ}$$

$$n = \frac{\Delta H}{\Delta H^{\circ}}$$

$$= \frac{-1.16 \times 10^{2}\ \cancel{\text{kJ}}}{\dfrac{-8.0 \times 10^{2}\ \cancel{\text{kJ}}}{\text{mol } CH_4(g)}}$$

$$= 0.145 \text{ mol } CH_4(g)$$

Use the conversion factor, 1 mol of any gas at STP occupies 22.4 L to find volume

$$\text{x L } CH_4(g) = 0.145\ \cancel{\text{mol } CH_4(g)} \times \frac{22.4 \text{ L } CH_4(g)}{\cancel{\text{mol } CH_4(g)}}$$

$$= 3.2 \text{ L } CH_4(g)$$

Method 2 Using Dimensional Analysis

$$\text{x L } CH_4(g) = 1.0 \times 10^{2} \text{ g } CaO(s) \times \frac{\text{mol } CaO(s)}{56.08 \text{ g } CaO(s)} \times \frac{-65\ \cancel{\text{kJ}}}{\cancel{\text{mol } CaO(s)}} \times \frac{\cancel{\text{mol } CH_4(g)}}{-8.0 \times 10^{2}\ \cancel{\text{kJ}}} \times \frac{22.4 \text{ L } CH_4(g)}{\cancel{\text{mol } CH_4(g)}}$$

$$= 3.2 \text{ L } CH_4(g)$$

32. (a) $C_{12}H_{22}O_{11}(s) + 12O_2(g) \rightarrow$

$$12CO_2(g) + 11H_2O(g)\ \Delta_c H = -5.65 \times 10^{3} \text{ kJ}$$

(b) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{5.00\ \cancel{\text{g } C_{12}H_{22}O_{11}(s)}}{\dfrac{342.34\ \cancel{\text{g } C_{12}H_{22}O_{11}(s)}}{\text{mol } C_{12}H_{22}O_{11}(s)}}$$

$$= 0.0146 \text{ mol } C_{12}H_{22}O_{11}(s)$$

$$\Delta H = n\Delta_c H$$

$$= (0.0146 \text{ mol } C_{12}H_{22}O_{11}(s)) \left(\frac{-5.65 \times 10^3 \text{ kJ}}{\text{mol } C_{12}H_{22}O_{11}(s)} \right)$$

$$= -82.5 \text{ kJ}$$

Method 2 Using Dimensional Analysis

$$x \text{ kJ} = 5.00 \text{ g } C_{12}H_{22}O_{11}(s) \times$$

$$\frac{1 \text{ mol } C_{12}H_{22}O_{11}(s)}{342.34 \text{ g } C_{12}H_{22}O_{11}(s)} \times \left(\frac{-5.65 \times 10^3 \text{ kJ}}{\text{mol } C_{12}H_{22}O_{11}(s)} \right)$$

$$= -82.5 \text{ kJ}$$

(c) $Q = mc\Delta t$

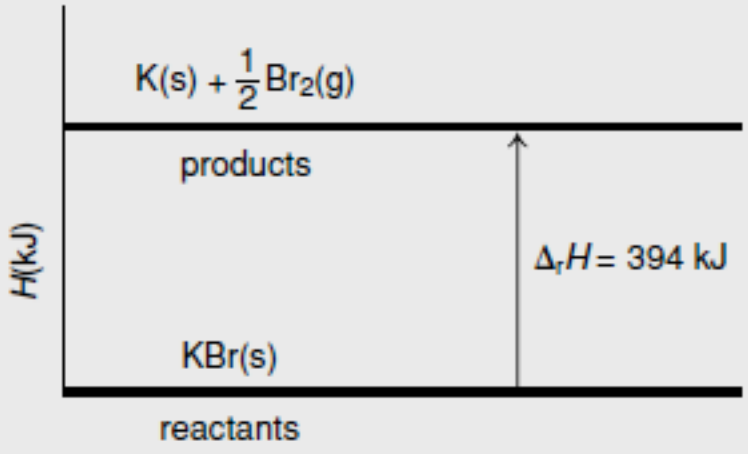
$$m = \frac{Q}{c\Delta t}$$

$$= \frac{82.5 \text{ kJ}}{\left(\frac{4.19 \text{ J}}{\text{g} \cdot ^\circ\text{C}} \right) \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) (5.0 \ ^\circ\text{C}) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right)}$$

$$= 3.9 \text{ kg}$$

33. (a) $KBr(s) \rightarrow K(s) + \frac{1}{2}Br_2(g) \quad \Delta H = 394 \text{ kJ}$

(b)



(c) If the molar enthalpy of decomposition is 394 kJ/mol, the molar enthalpy of formation is –394 kJ/mol.

Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{1.37 \text{ g KBr(s)}}{\frac{119.00 \text{ g KBr(s)}}{\text{mol KBr(s)}}}$$

$$= 0.0115 \text{ mol KBr(s)}$$

$$\Delta H = n\Delta_c H$$

$$= (0.0115 \text{ mol KBr(s)})\left(\frac{-394 \text{ kJ}}{\text{mol KBr(s)}}\right)$$

$$= -4.54 \text{ kJ}$$

Method 2 Using Dimensional Analysis

$$\text{x kJ} = 1.37 \text{ g KBr(s)} \times \frac{1 \text{ mol KBr(s)}}{119.00 \text{ g KBr(s)}} \times \frac{-394 \text{ kJ}}{\text{mol KBr(s)}}$$

$$= -4.54 \text{ kJ}$$

34. (a) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{1.37 \times 10^3 \text{ g } \cancel{\text{Fe(s)}}}{\frac{55.85 \text{ g } \cancel{\text{Fe(s)}}}{\text{mol Fe(s)}}}$$

$$= 24.5 \text{ mol Fe(s)}$$

$$\Delta H = n\Delta_c H^\circ$$

$$= (24.5 \text{ } \cancel{\text{mol Fe(s)}})\left(\frac{-1.65 \times 10^3 \text{ kJ}}{4 \text{ } \cancel{\text{mol Fe(s)}}}\right)$$

$$= -10.1 \times 10^3 \text{ kJ}$$

$$= -10.1 \text{ MJ}$$

Method 2 Using Dimensional Analysis

$$x\ \text{kJ} = 1.37 \times 10^3\ \cancel{\text{g Fe(s)}} \times \frac{1\ \cancel{\text{mol Fe(s)}}}{55.85\ \cancel{\text{g Fe(s)}}} \times \left(\frac{-1.65 \times 10^3\ \text{kJ}}{4\ \cancel{\text{mol Fe(s)}}}\right)$$

$$= -10.1 \times 10^3\ \text{kJ}$$

$$= -10.1\ \text{MJ}$$

(b) Method 1 Using Formulas

$$\Delta H = n\Delta H^\circ$$

$$n = \frac{\Delta H}{\Delta H^\circ}$$

$$= \frac{-3.75 \times 10^3\ \cancel{\text{kJ}}}{\dfrac{-1.65 \times 10^3\ \cancel{\text{kJ}}}{2\ \text{mol Fe}_2\text{O}_3\text{(s)}}}$$

$$= 4.545\ \text{mol Fe}_2\text{O}_3\text{(s)}$$

$$n = \frac{m}{M}$$

$$m = nM$$

$$= (4.545\ \cancel{\text{mol Fe}_2\text{O}_3\text{(s)}})\left(\frac{159.70\ \text{g Fe}_2\text{O}_3\text{(s)}}{\cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}}\right)$$

$$= 726\ \text{g Fe}_2\text{O}_3\text{(s)}$$

Method 2 Using Dimensional Analysis

$$x\ \text{g Fe}_2\text{O}_3\text{(s)} = -3.75 \times 10^3\ \cancel{\text{kJ}} \times \frac{2\ \cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}}{-1.65 \times 10^3\ \cancel{\text{kJ}}} \times \frac{159.7\ \text{g Fe}_2\text{O}_3\text{(s)}}{\cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}}$$

$$= 726\ \text{g Fe}_2\text{O}_3\text{(s)}$$

35. (a) greatest energy $C_8H_{18}(\ell)$, $C_2H_5OH(\ell)$, $CH_4(g)$, $H_2(g)$ least energy

(b) $C_8H_{18}(\ell) + \frac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(\ell)$

$\Delta_c H = -5\,513$ kJ/mol

$C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(\ell)$

$\Delta_c H = -1367$ kJ/mol

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$

$\Delta_c H = -890$ kJ/mol

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta_c H = -285$ kJ/mol

(c) To determine the heat content, divide each by the molar mass (in g/mol)

$$x\ \frac{\text{kJ}}{\text{g } C_8H_{18}(\ell)} = \frac{-5513\text{ kJ}}{\cancel{\text{mol } C_8H_{18}(\ell)}} \times \frac{\cancel{\text{mol } C_8H_{18}(\ell)}}{114.26\text{ g } C_8H_{18}(\ell)}$$

$$= -48.25\text{ kJ/g } C_8H_{18}(\ell)$$

$$x\ \frac{\text{kJ}}{\text{g } C_2H_5OH(\ell)} = \frac{-1367\text{ kJ}}{\cancel{\text{mol } C_2H_5OH(\ell)}} \times \frac{\cancel{\text{mol } C_2H_5OH(\ell)}}{46.08\text{ g } C_2H_5OH(\ell)}$$

$$= -29.66\text{ kJ/g } C_2H_5OH(\ell)$$

$$x\ \frac{\text{kJ}}{CH_4(g)} = \frac{-890\text{ kJ}}{\cancel{\text{mol } CH_4(g)}} \times \frac{\cancel{\text{mol } CH_4(g)}}{16.05\text{ g } CH_4(g)}$$

$$= -55.4\text{ kJ/g } CH_4(g)$$

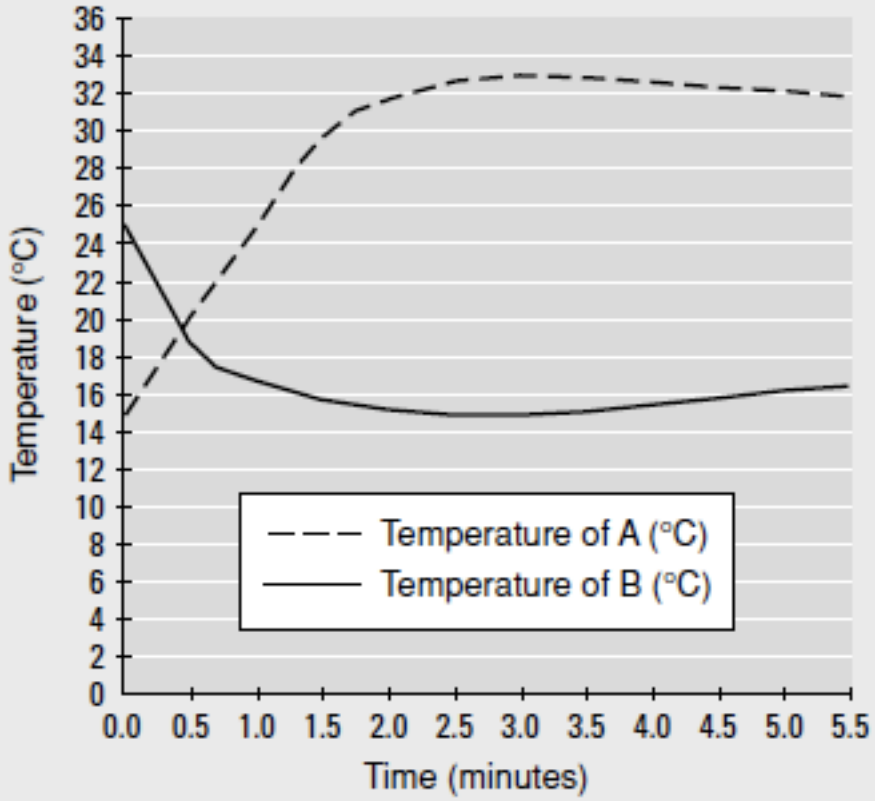
$$x\ \frac{\text{kJ}}{\text{g } H_2(g)} = \frac{-285\text{ kJ}}{\cancel{\text{mol } H_2(g)}} \times \frac{\cancel{\text{mol } H_2(g)}}{2.02\text{ g } H_2(g)}$$

$$= -141\text{ kJ/g } H_2(g)$$

greatest energy $H_2(g)$, $CH_4(g)$, $C_8H_{18}(\ell)$, $C_2H_5OH(\ell)$ least energy

(d) For most applications, heat content is likely more appropriate. Most people will buy fuel by mass or volume, so knowing how much energy a litre or kilogram will provide is more useful than the measurement in moles. Another useful measurement would be based on fuel costs (kJ/$) or on emissions produced (kJ/kg $CO_2(g)$).

36. (a) Change in temperature as solids A & B are dissolved



(b) When solid A dissolves, the temperature increases. Therefore, the enthalpy of solution of solid A is exothermic. When solid B dissolves, the temperature decreases. Therefore, the enthalpy of solution of solid B is endothermic.

(c) For A, the maximum temperature is 33.0 °C.

$$\Delta t = 33.0\ ^\circ\text{C} - 15.0\ ^\circ\text{C}$$
$$= 18.0\ ^\circ\text{C}$$

$$n\Delta H = mc\Delta t$$

$$\Delta H = -\frac{(110\ \cancel{g})\left(\frac{4.19\ \text{J}}{\cancel{g}\cdot\cancel{^\circ\text{C}}}\right)(18.0\ \cancel{^\circ\text{C}})}{10.0\ \text{g A(s)}}$$

$$= -830\ \text{J/g A(s)}$$

For B, the minimum temperature is 15.0 °C.

$$\Delta t = 15.0\ ^\circ\text{C} - 25.0\ ^\circ\text{C}$$
$$= -10.0\ ^\circ\text{C}$$

$$n\Delta H = mc\Delta t$$

$$\Delta H = -\frac{(110\ \cancel{g})\left(\frac{4.19\ \text{J}}{\cancel{g}\cdot\cancel{^\circ\text{C}}}\right)(-10.0\ \cancel{^\circ\text{C}})}{10.0\ \text{g B(s)}}$$

$$= 461\ \text{J/g B(s)}$$

(d) Both plots indicate that the calorimeter is not a perfect insulator. The graph for solid A evidently rises above room temperature and then begins to fall. The graph for solid B falls below room temperature and then begins to rise.

37.

$3\times\ 3\text{C(s)} + 6\text{H}_2\text{(g)} \rightarrow 3\text{CH}_4\text{(g)}$ $\quad \Delta H^\circ = -74.8\ \text{kJ} \times 3$

$2\times\ 2\text{H}_2\text{(g)} + \text{O}_2\text{(g)} \rightarrow \cancel{2\text{H}_2\text{O}}\text{(g)}$ $\quad \Delta H^\circ = -241.8\ \text{kJ} \times 2$

$-2\times\ \cancel{2\text{H}_2\text{O}}\text{(g)} \rightarrow 2\text{H}_2\text{O}(\ell)$ $\quad \Delta H^\circ = 44.0\ \text{kJ} \times -2$

$\text{CO(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$ $\quad \Delta H^\circ = -283.1\ \text{kJ}$

$-3\times\ 3\text{CO(g)} \rightarrow 3\text{C(s)} + \frac{3}{2}\cancel{\text{O}_2}\text{(g)}$ $\quad \Delta H^\circ = -110.5\ \text{kJ} \times -3$

$$4CO(g) + 8H_2(g) \rightarrow 3CH_4(g) + CO_2(g) + 2H_2O(\ell) \qquad \Delta H^\circ = -747.6 \text{ kJ}$$

38. $-1 \times (4)$ $\quad H_2S(g) \rightarrow \cancel{H_2(g)} + \frac{1}{\cancel{8}}\cancel{S_8(s)} \qquad \Delta H^\circ = -21 \text{ kJ} \times -1$

$2 \times (2)$ $\quad H_2(g) + F_2(g) \rightarrow 2HF(g) \qquad \Delta H^\circ = -273 \text{ kJ} \times 2$

(3) $\quad \frac{1}{\cancel{8}}\cancel{S_8(s)} + 3F_2(g) \rightarrow SF_6(g) \qquad \Delta H^\circ = -1220 \text{ kJ}$

$$H_2S(g) + 4F_2(g) \rightarrow 2HF(g) + SF_6(g) \qquad \Delta H^\circ = -1745 \text{ kJ}$$

39. (a) $\Delta_r H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$= [(1 \text{ mol})(\Delta_f H^\circ \ CaCO_3(s))] -$

$[(1 \text{ mol})(\Delta_f H^\circ \ CaO(s)) + (1 \text{ mol})(\Delta_f H^\circ \ CO_2(g))]$

$= [(1 \text{ mol})(-1207.6 \text{ kJ/mol})] -$

$[(1 \text{ mol})(-634.9 \text{ kJ/mol}) + (1 \text{ mol})(-393.5 \text{ kJ/mol})]$

$= -179.2 \text{ kJ}$

(b) $\Delta_r H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$= [(1 \text{ mol})(\Delta_f H^\circ \ C_2H_6(g))] -$

$[(1 \text{ mol})(\Delta_f H^\circ \ C_2H_2(g)) + (2 \text{ mol})(\Delta_f H^\circ \ H_2(g))]$

$= [(1 \text{ mol})(-84.0 \text{ kJ/mol})] -$

$[(1 \text{ mol})(227.4 \text{ kJ/mol}) + (2 \text{ mol})(0 \text{ kJ/mol})]$

$= -311.4 \text{ kJ}$

(c) $\Delta_r H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$= [(4 \text{ mol})(\Delta_f H^\circ \ NO(g)) +$

$(6 \text{ mol})(\Delta_f H^\circ \ H_2O(g))] -$

$[(4 \text{ mol})(\Delta_f H^\circ \ NH_3(g)) + (5 \text{ mol})(\Delta_f H^\circ O_2(g))]$

$= [(4 \text{ mol})(91.3 \text{ kJ/mol}) +$

$(6 \text{ mol})(-241.8 \text{ kJ/mol})] -$

$[(4 \text{ mol})(-45.9 \text{ kJ/mol}) + (5 \text{ mol})(0 \text{ kJ/mol})]$

$= -902.0 \text{ kJ}$

40. $\Delta_r H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$$-182.6 \text{ kJ} = [(1 \text{ mol})(\Delta_f H^\circ \text{ SiF}_4(g)) + (2 \text{ mol})(\Delta_f H^\circ \text{ H}_2\text{O}(\ell))] - [(1 \text{ mol})(\Delta_f H^\circ \text{SiO}_2\text{ (g)}) + (4 \text{ mol})(\Delta_f H^\circ \text{HF(g)})]$$

$$-182.6 \text{ kJ} = [(1 \text{ mol})(\Delta_f H^\circ \text{SiF}_4(g)) + (2 \text{ mol})(-285.8 \text{ kJ/mol})] - [(1 \text{ mol})(-910.7 \text{ kJ/mol}) + (4 \text{ mol})(-273.3 \text{ kJ/mol})]$$

$$-182.6 \text{ kJ} = (1 \text{ mol})(\Delta_f H^\circ \text{ SiF}_4(g)) + 1432.3 \text{ kJ}$$

$$\Delta_f H^\circ \text{ SiF}_4(g) = -1614.9 \text{ kJ/mol SiF}_4(g)$$

41. (a) $C_3H_5(NO_3)_3(\ell) \rightarrow \frac{3}{2}N_2(g) + \frac{5}{2}H_2O(g) + 3CO_2(g) + \frac{1}{4}O_2(g)$ $\Delta H = -1.15 \times 10^4 \text{ kJ/mol } C_3H_5(NO_3)_3(\ell)$

(b) $\Delta H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$$-1.15 \times 10^4 \text{ kJ} = \left[\left(\frac{3}{2} \text{ mol}\right)(\Delta_f H^\circ \text{ N}_2(g)) + \left(\frac{5}{2} \text{ mol}\right)(\Delta_f H^\circ \text{ H}_2\text{O(g)}) + (3 \text{ mol})(\Delta_f H^\circ \text{ CO}_2(g)) + \left(\frac{1}{4} \text{ mol}\right)(\Delta_f H^\circ \text{ O}_2(g))\right] - [(1 \text{ mol})(\Delta_f H^\circ \text{ C}_3\text{H}_5(\text{NO}_3)_3(\ell))]$$

$$-1.15 \times 10^4 \text{ kJ} = \left[\left(\frac{3}{2} \text{ mol}\right)(0 \text{ kJ/mol}) + \left(\frac{5}{2} \text{ mol}\right)(-241.8 \text{ kJ/mol}) + (3 \text{ mol})(-393.5 \text{ kJ/mol}) + \left(\frac{1}{4} \text{ mol}\right)(0 \text{ kJ/mol}\right] - [(1 \text{ mol})(\Delta_f H^\circ \text{ C}_3\text{H}_5(\text{NO}_3)_3(\ell))]$$

$$-1.15 \times 10^4 \text{ kJ} = -1785.0 \text{ kJ} - (1 \text{ mol})(\Delta_f H^\circ \text{ C}_3\text{H}_5(\text{NO}_3)_3(\ell))$$

$$\Delta_f H^\circ C_3H_5(NO_3)_3(\ell) = 9.72 \times 10^3 \text{ kJ/mol } C_3H_5(NO_3)_3(\ell)$$

42. (a) –22 kJ

(b) 5.76 g $O_2(g)$

(c) $C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

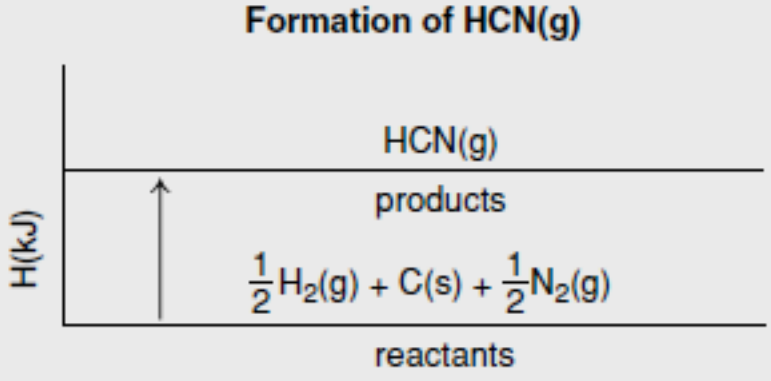
$\Delta_c H = -1234.8$ kJ/mol

(d) 20.5 g $C_2H_5OH(\ell)$

43. (a) $\frac{1}{2}H_2(g) + C(s) + \frac{1}{2}N_2(g) \rightarrow HCN(g)$

$\Delta H = 135$ kJ/mol

(b)



(c) 301 kJ

44. The theoretical value for the molar enthalpy of combustion of propane, $C_3H_8(g)$, in an open system can be calculated:

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

$\Delta_c H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{reactants})$

$= [(3 \text{ mol})(\Delta_f H^\circ CO_2(g)) + (4 \text{ mol})(\Delta_f H^\circ H_2O(g))] - [(1 \text{ mol})(\Delta_f H^\circ C_3H_8(g)) + (5 \text{ mol})(\Delta_f H^\circ O_2(g))]$

$= [(3 \text{ mol})(-393.5 \text{ kJ/mol}) + (4 \text{ mol})(-241.8 \text{ kJ/mol})] - [(1 \text{ mol})(-103.8 \text{ kJ/mol}) + (5 \text{ mol})(0 \text{ kJ/mol})]$

$= -2043.9$ kJ/mol $C_3H_8(g)$

Energy Input Calculation:

Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{4.48 \text{ g } C_3H_8(g)}{\frac{44.11 \text{ g } C_3H_8(g)}{\text{mol } C_3H_8(g)}}$$

$$= 0.1016 \text{ mol } C_3H_8(g)$$

$$\Delta H = n\Delta_c H$$

$$= (0.1016 \cancel{\text{mol } C_3H_8(g)})\left(\frac{-2043.9 \text{ kJ}}{\cancel{\text{mol } C_3H_8(g)}}\right)$$

$$= -208 \text{ kJ}$$

Method 2 Using Dimensional Analysis

$$\text{x kJ} = \frac{-2043.9 \text{ kJ}}{\cancel{\text{mol } C_3H_8(g)}} \times \frac{1 \cancel{\text{mol } C_3H_8(g)}}{44.11 \text{ g } \cancel{C_3H_8(g)}} \times 4.48 \cancel{\text{g } C_3H_8(g)}$$

$$= -207 \text{ kJ}$$

Energy Output Calculation:

$$Q = mc\Delta t_{soup} + mc\Delta t_{steel}$$

$$= (275.37 \cancel{\text{g}})\left(\frac{3.57 \text{ J}}{\cancel{\text{g}}^{\bullet}\cancel{^\circ\text{C}}}\right)(75.4 \cancel{^\circ\text{C}} - 4.5 \cancel{^\circ\text{C}}) + (575.00 \cancel{\text{g}})\left(\frac{0.503 \text{ J}}{\cancel{\text{g}}^{\bullet}\cancel{^\circ\text{C}}}\right)(75.4 \cancel{^\circ\text{C}} - 4.5 \cancel{^\circ\text{C}})$$

$$= 90.2 \text{ kJ}$$

Efficiency Calculation:

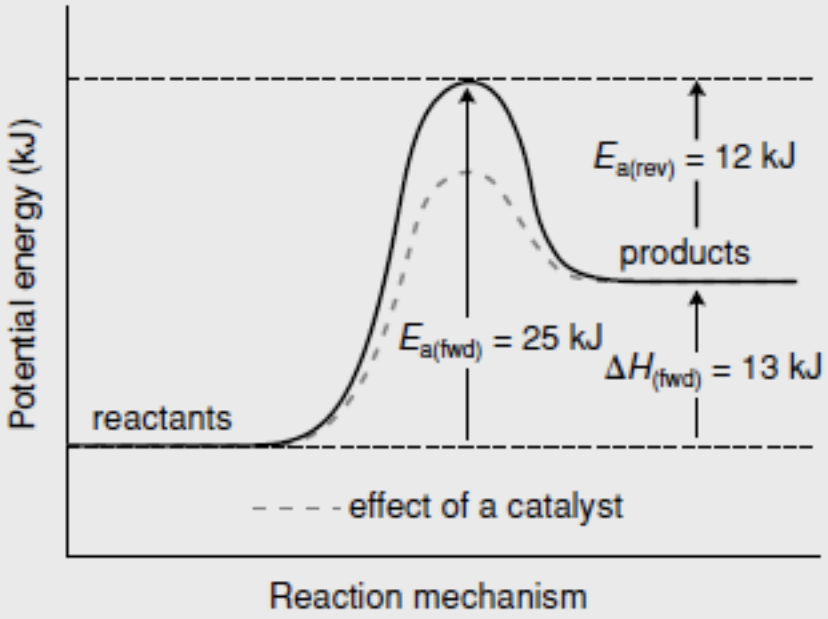
$$\text{Efficiency} = \left| \frac{\text{Energy output}}{\text{Energy input}} \right| \times 100\%$$

$$= \left| \frac{90.2 \cancel{\text{kJ}}}{-208 \cancel{\text{kJ}}} \right| \times 100\%$$

$$= 43.4\%$$

In order to improve the camp stove's efficiency, the heat lost to the surroundings must be decreased. Adding a lid to the pot would prevent heat loss from the soup to the air. The pot should be placed very close to the flame, and if possible, sides could be added to the stove to better direct the hot air towards the pot.

45. (a)



(b) The activation energy for the reverse reaction is 25 kJ − 13 kJ = 12 kJ.

(c) See figure above.

Answers to Making Connections Questions

46. (a) Some examples are shown in the table below. Students should take note of the engine size and number of cylinders as well as the type of transmission.

Year	Make/ model	Engine size/ cylinders	Transmission	City consumption (L/100 km)	Highway consumption (L/100 km)
2006	Chrysler PT Turbo Conver-tible	2.4 / 4	automatic	11.40	8.10
2006	Chrysler PT Turbo Conver-tible	2.4 / 4	manual	10.40	7.90
2006	Chrysler PT Turbo Conver-tible	2.4 / 4	auto with manual	11.40	8.10
2006	Chrysler Sebring Conver-tible	2.7 / 6	automatic	11.20	7.80
2006	Chrysler Sebring Conver-tible	2.7 / 6	auto with manual	11.10	7.70

Year	Make/ model	Engine size/ cylinders	Transmission	City consumption (L/100 km)	Highway consumption (L/100 km)
2006	Ford Focus	2.0 / 4	manual	9.00	6.40
2006	Ford Focus	2.3 / 4	manual	10.60	6.90
2006	Honda Civic	1.8 / 4	automatic	8.20	5.70
2006	Honda Civic	1.8 / 4	manual	7.80	5.70
2006	Honda Civic Hybrid	1.3 / 4	variable	4.70	4.30
2006	Honda Civic Si	2.0 / 4	manual	10.20	6.80
2006	Mazda 3	2.0 / 4	manual	8.40	6.10
2006	Mazda 3	2.0 / 4	auto with manual	9.10	6.40
2006	Mazda 3	2.3 / 4	manual	9.20	6.70
2006	Mazda 3	2.3 / 4	auto with manual	9.40	6.90

(b) The following options should be considered, although students are asked what concessions they are willing to make to improve fuel efficiency.

- smaller/lighter car
- smaller engine
- fewer cylinders
- hybrid instead of gasoline

(c) A car will operate at its maximum fuel efficiency if it is well-maintained and has its tires inflated to the proper pressure. By driving at or below the speed limit and by not accelerating or decelerating quickly, a driver can further improve fuel efficiency.

47. You would need to consider:

- the relative safety of the fuels
- the ratio of the dollar cost of the fuel per kJ of useful fuel delivered
- the cost of maintaining the furnace
- the environmental impact of the fuel: How is the fuel obtained? How much energy is expended in order to deliver the fuel? What kinds and what quantities of by-products are produced?

You would assume the delivery and availability of each fuel would be the same.

48. First, find the volume of the gas in litres:

$$\text{Volume } CH_4(g) = (0.95 \times 10^3 \cancel{ft^3})(12 \cancel{in}/\cancel{ft})^3 (1\text{ L}/1000 \cancel{cm^3})(2.54 \cancel{cm}/\cancel{in})^3$$

$$= 2.7 \times 10^4 \text{ L}$$

$$\text{The amount of methane} = 2.7 \times 10^4 \text{ L} \times \frac{\text{mol}}{24 \text{ L}}$$

$$= 1.1 \times 10^3 \text{ mol}$$

$\Delta_c H$ for $CH_4(g) = -803$ kJ/mol

The amount of energy released by burning 1.1×10^3 mol of $CH_4(g)$ can be determined:

$$\Delta H = n\Delta_c H$$
$$= 1.1 \times 10^3 \text{ mol } CH_4(g) \times -803 \text{ kJ\mol } CH_4(g)$$
$$= 8.8 \times 10^5 \text{ kJ}$$

This is approximately 10×10^5 kJ, which is 1 GJ. The claim is probably valid.

49. Student answers should include (or all) of the following information. Pepsin is a protein digesting enzyme that is produced by the cells of the stomach. It functions most effectively at a pH between 1 and 3. Pepsin breaks large proteins into smaller ones called peptides. Lipase is a fat digesting enzyme. It is produced by the pancreas and other cells in the body. Its role is to break down lipids into its component parts, glycerol and triglycerides. Pancreatic lipase functions optimally at a pH of 8.0. Other lipases, including stomach lipase, are most effective at a lower pH.